VEHICLE AND SURVIVAL FACTORS ATTACHMENT 5 – MOUNTAIN VIEW FD SAFETY ALERT

Mountain View, CA

HWY18FH011

(14 pages)

CITY OF MOUNTAIN VIEW

OFFICE OF THE FIRE CHIEF • FIRE DEPARTMENT - CLASS 1
1000 Villa Street • Mountain View • California • 94041-1295
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MEMORANDUM#43-18

Fire Department

DATE: April 5, 2018

TO: All Personnel

FROM: Juan F. Diaz, Fire Chief

SUBJECT: **Safety Alert – Electric Vehicles High-Voltage Battery Fire**

ACTION

All officers are to review with their crews and post in the fire stations.

BACKGROUND

On March 23, 2018, the Mountain View Fire Department responded to a MVA SB101 at Highway 85 involving three vehicles. One of the vehicles involved was an electric vehicle (EV), a Tesla Model X. On the arrival of E55, the electric vehicle's 400-volt battery pack had significant intrusion due to the collision, it was clearly damaged, and it was also on fire. The driver, the single occupant of the Model X, had been extricated by other motorists and was unconscious. There were no other victims. E53 and E55 personnel rendered care and extinguished the vehicle and battery fire with approximately 200 gallons of water. It was noted that full extinguishment of the EV occurred within two minutes. Water application to the exposed battery pack was stopped after approximately 10 minutes of being on scene due to no obvious signs of fire in the battery. The critically injured driver was transported to Stanford Hospital Trauma Center in the care of two MVFD Firefighter Paramedics. The patient, despite efforts, later succumbed to his injuries in the ER.

CHALLENGES ON SCENE

1. While the actual flames emanating from the battery were extinguished, there was no practical means to deenergize the damaged Lithium-ion battery cells as there was no access to all of the battery. In addition, first responders are not qualified for such deenergizing process. Deenergizing may be accomplished by disassembly of the battery cells one by one or by connecting to the battery to an electrical appliance and performing a battery draw down. Both of these procedures are not within the scope of MVFD personnel.

2. The damaged battery presented a concern of electric shock as many of the cells and high voltage wires were exposed.

3. Due to the short-circuit event that had occurred when the battery's interior was breached in the collision, the battery cells continued to generate heat in a known deenergizing process called "thermal runaway."

Faced with this dilemma, the IC opted to have the vehicle's manufacturer respond to the scene to provide their expertise in eliminating the thermal runaway and electrical hazards. After approximately two hours into the event, Tesla engineers arrived and attempted to dismantle as much of the damaged battery cells/modules as they could. They meticulously removed each cell, one by one. Approximately 25 percent of the battery was removed and several of its high-voltage wires had been isolated. However, the rest of the battery's cells were not accessible without removal of the main battery from the vehicle and the determination was made that the vehicle was safe enough to be towed. At approximately 5-1/2 hours into the event, the vehicle was safely towed to the CHP impound yard with an escort from MVFD E55. The escort was necessary due to the potential for reignition as not all of the battery cells had been removed. During transport, the battery continued to exhibit signs of deenergizing, but no reignition occurred during transport. However, the battery reignited (twice) in the storage yard during its first 24 hours and reignited again six days later on Thursday, March 29, 2018.

Picture prior to FD arrival

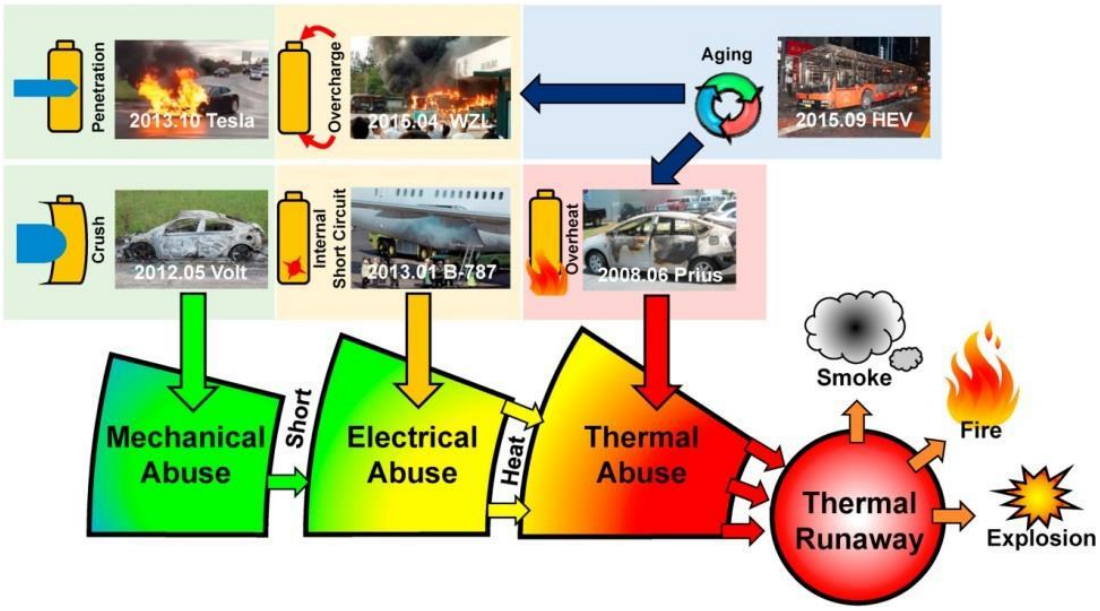
Damaged battery front bottom

GENERAL INFORMATION ON LITHIUM-ION BATTERIES IN EV

The Lithium-ion battery is the most typical power product for the electrified vehicle powertrain system today. These batteries, up to 8,200 units (in the Model X), comprised the Tesla battery pack. They can range from 100 to 500 plus volts.

Lithium-Ion Battery Thermal Runaway: A "Thermal Runaway" is a term used when a battery cell suffers a short circuit, the battery heats up and continues to produce heat, even when it is extinguished and/or submerged in water.

- A Lithium-ion battery is subject to thermal runaway when it has been damaged from either penetration or crushing in a collision, exposed to heat, or internal short circuit due to a factory defect or aging.
- In the last five years, several EV fires have occurred throughout the world involving Lithium-ion batteries. These batteries will continue to dissipate heat during their deenergizing and will not stop until completely deenergized.
- During a thermal runaway event, temperatures can exceed over 900 degrees Fahrenheit. The battery cell itself will suffer a self-destruction of its structure (these are small explosions and "pop" noises Firefighters may hear) and the gases and heat produced will cause the module casing to vent (these are the "thump" noises Firefighters may hear on the scene as the modules' pressure caps open up).
- Unless a Lithium battery pack is completely disassembled and deenergized a thermal runaway will promulgate to other batteries and the rest of the battery pack will continue to burn.
- In Mountain View Fire Department, the Tesla X battery reignited six days later. Two weeks later, the NTSB and Tesla performed a battery draw down to fully deenergized the involved battery in an effort to avoid further reignition.



Examples of Lithium-ion thermal runaway fires

EV bus in China

BMW i3 in a Norwegian test

E Smart car on a charger in the UK

Zotye taxi in China

Tunnel entrance in Austria with a Tesla on fire

FACTS ABOUT EV AND FIRES:

- NFPA statistics show that about 90 cars catch fire for every 1 billion miles driven in the United States.

- In the first billion miles driven by Teslas (mid-2015), there were three fires. Based on these statistics, an EV is less likely to ignite in a collision than an internal combustion engine vehicle.

- Fires have occurred in several EV vehicles in the United States and the world primarily due to high-speed impacts.

CHALLENGES FOR THE FIRE SERVICE:

1. An exposed EV battery, its wiring and components can kill anyone that comes in contact with it. The high-voltage direct current (DC) will cause a lethal electrical shock.

2. Any EV and hybrid internal combustion-electric vehicles may be electrically energized in a collision if the main DC battery and/or its wiring have been damaged to the degree where they have come in contact with any of the vehicle's metal surfaces. As a result, all personnel shall not come in contact with any of the batteries or its components until it is verified that it is deenergized.

3. The fire service is not currently equipped to fully disassemble and disable a lithium-ion battery. These batteries, when damaged, will continue to burn for hours and, depending how fully charged the batteries may be, in some cases they may be in thermal runaway for days and reignite.

4. The Mountain View Fire Department is currently seeking the procurement of a DC Hot Stick to assist in detecting if a vehicle is energized. The U.S. Department of Energy's Oak Ridge National Laboratory is addressing this new challenge with the development of a DC probe to accurately detect DC energy.

DC Hot Stick prototype being developed by the U.S. Department of Energy

5. More and more of these vehicles are being produced; we can expect an increase in accidents with intrusions and damage of these Lithium-ion batteries. These vehicles will be parked inside residential garages and businesses. If a structure is on fire and the fire extends or involves an area where an EV is parked, you can expect damage to the EV Lithium-ion battery and subsequently experience a thermal runaway.

6. The on scene time to address an EV battery thermal runway event is significantly higher than a fire involving an internal combustion engine vehicle. MVFD can expect extended on scene time to mitigate an EV battery fire.

ACTION EV COLLISION AND/OR FIRE:

1. **Hazards to First Responders:** NFPA has conducted research on vehicle fires involving EV. Results have shown that even when the EV battery was on fire, no electricity was transmitted through the water stream and nozzle back to the Firefighters. However, to ensure there is no potential for such transmission of electricity to the Firefighter, MVFD personnel shall stay at least 20' away when extinguishing an EV fire with water only until extinguishment is obtained. Always consider the vehicle as energized.

2. **Cooling Process:** Cooling of the battery's modules and cells is an effective manner in preventing reignition. During NFPA testing, it was determined that it could take 2,600 and up to 3,000 gallons to effectively cool down the battery. However, this cooling can only take place as long as the water is introduced inside the battery. Use of the thermal imager camera can facilitate the status of the internal thermal runaway and determine if temperatures are going up or down.

    a. If a battery is mostly still intact, as was the case in our EV fire, it will be nearly impossible to penetrate all of the modules and cells. Thus, expect reignition

of the battery to occur for days. One option to ensure penetration into the battery is to completely submerge the battery in water. This can be accomplished by creating a dam around the vehicle and filling the dam with water, ensuring the battery is fully submerged.

3. **Electrocution Hazard:** Due to the potential for electrocution, MVFD personnel **shall not** come in contact with any EV batteries or its components damaged in a vehicle accident until is it verified that it is 100 percent deenergized.

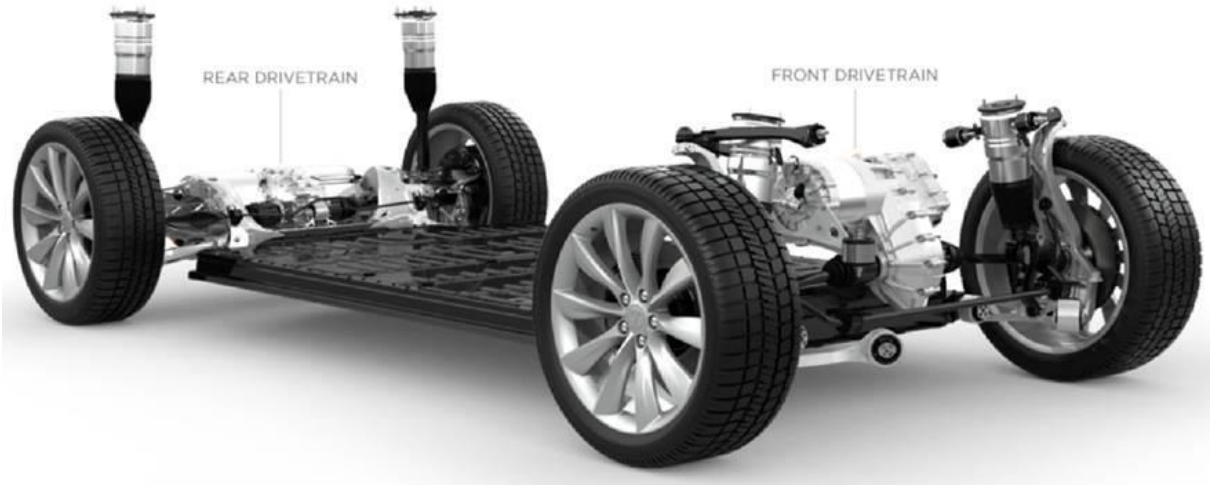
4. **First Responders Loop:** In all vehicle accidents involving an EV or Hybrid EV/Combustion vehicles, MVFD personnel shall first make an attempt to disconnect the main DC electrical battery at the vehicle's "first responder loop." Consult with the vehicle manufacturer for the location of the first responder loop and double cut the wiring to ensure they will not retouch.

WARNING: Always consider all high-voltage wiring energized and do not touch the wires.

5. **Do not use foam.** Foam has its place but can be counterproductive. It is intended to smother a fuel by eliminating an oxygen source and break down the viscosity of water for deeper penetration. However, Lithium-ion batteries have their own fuel and oxygen built in. As a result, a layer of foam can actually insulate the hot area to prevent further cooling. Per NTSB, FAA testing with laptop computers found that the foam could be less effective than just using water.

6. **Use Low Water Pressure:** The goals are to knock down flames of the car fire (mostly plastics) and cool the source of heat within the battery. For successful battery extinguishment, basic engineering remains that liquid under high pressure (nozzle pressure of over 50 psi) is less effective for prevention of heat transfer in a large battery than steady flow or low pressure. Ideally, the battery cell temperatures would be brought down to less than water's boiling point to get below the temperature at which the plastic in the cells melts because melting out the plastic separator is what ultimately allows a thermal event to progress. The reality is that we do not actually have access to the interior of the cells (normally) because they are in the cased assembly, but the concept of heat transfer still means keeping a steady low pressure flow. The source for thousands of gallons of water may also be an issue. In that light, to conserve water and have a more effective cooling, MVFD personnel will use a low-flow fog (see University of Maryland reference) rather than a high-pressure straight stream.

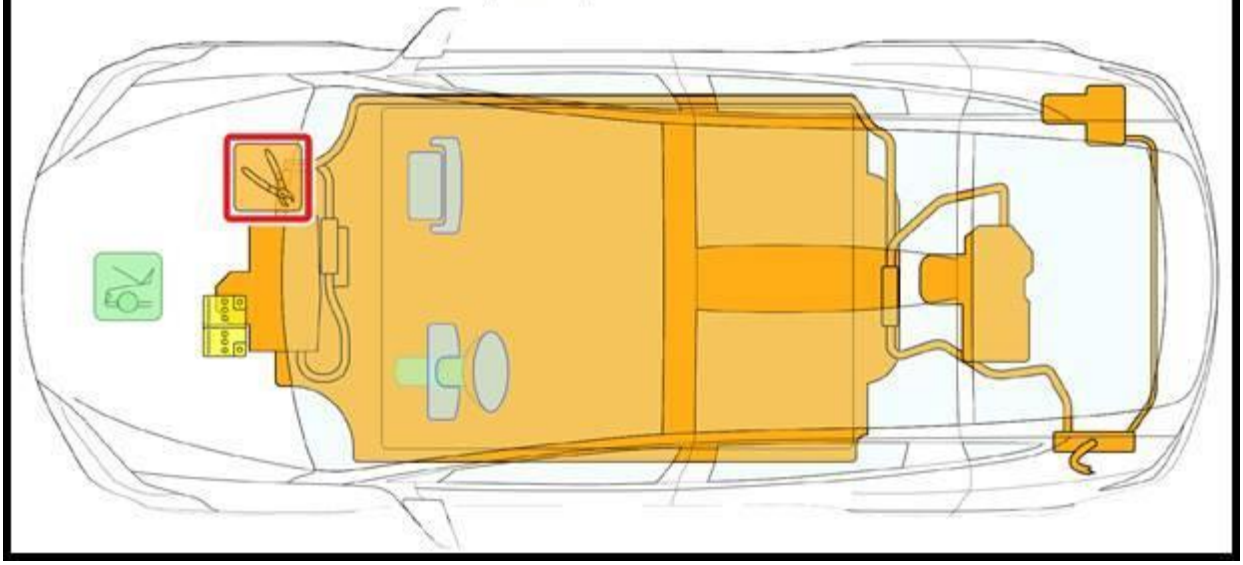
NOTE: *In this accident and fire in Mountain View, the "First Responder Loop," (which is the low-voltage harness made available to shut down the high voltage system in a Tesla), was destroyed on impact and, thus, Firefighters were not able to disconnect the high-voltage battery. However, even if we had access to cut the "First Responder Loop" we would still have the extinguishment challenge of a damaged battery and its thermal runaway event.*



Typical Tesla electrical engines and battery

FRONT TRUNK FIRST RESPONDER CUT LOOP

The first responder loop is a low voltage harness. Cutting the first responder loop shuts down the high voltage system outside of the high voltage battery and disables the SRS and airbag components. Refer to Cutting the Front Trunk First Responder Loop on page 14 for instructions on how to access and cut the first responder loop.



CUTTING THE FIRST RESPONDER LOOP

STEP 1: Open the hood (also known as the Front Trunk). See page 21 for details.

The cut loop is located on the right side. Its label protrudes from under the plastic access panel.

STEP 2: Remove the access panel by pulling its rear edge upward to release the five clips that hold it in place. Maneuver it toward the windshield to remove.

STEP 3: **DOUBLE CUT** the loop to remove an entire section.

Removing an entire section of the cut loop eliminates the risk of the wires accidentally touching (reconnecting).

WARNING: Regardless of the disabling procedure you use, ALWAYS ASSUME THAT ALL HIGH VOLTAGE COMPONENTS ARE ENERGIZED! Cutting, crushing or touching high voltage components can result in serious injury or death.

Remember to always avoid contact with a damaged high-voltage (HV) battery as a significant shock hazard may exist. An HV battery should always be considered to contain a charge and should never be touched or pried open.

Damaged EV Battery – Source: NFPA

DAMAGED HV BATTERIES (From NFPA)

- If damaged, HV batteries may give off harmful and/or flammable fumes.
- If you detect unusual odors or experience eye, nose, throat, or skin irritation, don full PPE with SCBA (Note: MVFD personnel shall always arrive on scene in full PPE).
- If you detect leaking fluids, sparks, smoke, or bubbling noises coming from the HV battery, ventilate the vehicle by opening the windows and trunk to prevent the buildup of fumes.
- Sparks, smoke, or bubbling noises coming from the HV battery are signs of a potentially overheating battery, which could result in a delayed fire.
- Contents of HV batteries should be considered corrosive, toxic, and/or flammable.

Avoid contact with a damaged HV battery; a significant shock hazard may exist.

FIRE IN A HYBRID AND ELECTRIC VEHICLES GENERAL (From NFPA)

- Hybrid and electric vehicles do not require special equipment for fire suppression/extinguishment.

- Difficulty in extinguishing an HV battery fire is dependent on several factors:
  - Size and location of battery.
  - Extent of fire within the battery.
  - Access and ability of extinguishing agent to be applied to the battery assembly case.
  - Potential openings in battery case that allow extinguishing agent to be placed directly on the burning cells.

EXTINGUISHING AGENTS

- Use water.
- The use of water does not present an electrical hazard to firefighting personnel.
- If an HV battery catches fire, it will require a large, sustained volume of water. Testing has indicated it could require over 2,600 gallons, depending on the size and location of the battery. Be sure to establish a sustained water supply through a hydrant or static water source.

THE U.S. FIRE ADMINISTRATION OFFERS THESE TIPS WHEN DEALING WITH CRASHES INVOLVING HYBRID VEHICLES:

- Always assume the vehicle is powered-up despite no engine noises.
- Put vehicle in park, turn ignition off, and remove key to disable the high-voltage system.
- Consider the electrical system unsafe for a full five minutes after ignition shutdown.
- Never touch, cut, or open any orange cable or components protected by orange shields.
- Remain a safe distance from vehicle if it is on fire.

ADDITIONAL RESOURCES

Most EV manufacturers have an emergency response guide which a quick Internet search can find. This is important for arriving crews to know where high-voltage

equipment and cut-loops are. Unfortunately, this is not always true and an example would be Chinese BYD, which is a company making electric buses in Lancaster, California. Currently, there's no first responders loop in these vehicles.

Examples of guidance:

- BMW i3 response guidance:
  https://www.nfpa.org/-/media/Files/Training/AFV/Emergency-Response-Guides/BMW/BMWi3rescue-guidelinefinal20131218EN.ashx?la=en

- Chevy Bolt and Volt response guides:
  https://www.gmstc.com/FirstResponder.aspx

- Ford EV response guide:
  https://www.fleet.ford.com/resources/ford/general/pdf/emergency-response-guides/2017-Focus-BEV-Emergency-Response-Guide.pdf

- Nissan LEAF response guidance:
  https://www.nfpa.org/-/media/Files/Training/AFV/Emergency-Response-Guides/Nissan/2015NissanLEAFFRG.ashx?la=en&hash=68682777E4AC9302398373AE4914E9CD3AA5AA6F

- Smart electric (and other Mercedes products):
  https://xentryportal.i.daimler.com/public/dateien_altsystem/common/info/info_rettung/emergency_response/Emergency_Response_Guide_smart_fortwo_electric_drive_pdf.pdf

- Tesla response guidance:
  https://www.tesla.com/firstresponders

Plus:

- SFPE testing by University of Maryland:
  http://www.sfpe.org/?page=2014_Q2_3
  The references at the end link to more good practical info.

- NTSB 787 investigation lessons learned:
  https://naatbatt.org/787-battery-investigation/

CLOSING

EV and hybrid vehicles are being mass-produced, and there are over 3 million of these vehicles in the United States. We can expect additional millions of these vehicles on our

roadways in the coming years. Several delivery/service EV and hybrid trucks and buses are already on the road with thousands more being ordered. Currently, MVFD does not have the tools to detect electricity in an EV and hybrid DC systems; this is a very serious hazard to first responders.

Mountain View Firefighters shall use extreme caution when working on an EV and/or hybrid vehicle that has been severely damaged and avoid contact with any exposed and/or damaged battery, its components and wiring. Treat all EV and hybrid vehicles in severe collisions as always energized.